AD-A047 540 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 13/13
APPROXIMATE CALCULATION OF THE THERMAL REGIME OF RESERVOIRS FOR--ETC(U)
NOV 77 A I PEKHOVICH, L I KUDOYAROV

UNCLASSIFIED CRREL-TL-662 NL

| OF |

AD
A047540

END
DATE
FILMED
1 -78
DDC

CRREL

Draft Translation 662
November 1977

12

APPROXIMATE CALCULATION OF THE THERMAL REGIME OF RESERVOIRS FORMED BY A FROZEN DAM

A.I. Pekhovich et al

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Draft Translation 662	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) APPROXIMATE CALCULATION OF THE THERMAL REGIME OF RESERVOIRS FORMED BY A FROZEN DAM	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A.I. Pekhovich, et al	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE November 1977
	13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

RESERVOIRS
THERMAL REGIME
EARTH DAMS
PERMAFROST BENEATH DAMS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The goal of this paper is to provide a general scheme and practical method for calculating the thermal regime of a reservoir, taking into consideration interaction with the dam and the foundation. It also examines the possibility of regulating the thermal regime of the structure.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DRAFT TRANSLATION 662

6

ENGLISH TITLE: APPROXIMATE CALCULATION OF THE THERMAL REGIME OF RESERVOIRS FORMED BY A FROZEN DAM

FOREIGN TITLE: (PRIBLIZHENNYI RASCHET TEPLOVOGO REZHIMA VODOKHRANILISHCH OBRAZOVANNYKH POMOROZHENNOI PLOTINOI)

19 | 11 Nov 77

AUTHOR: A.I./Pekhovich, et al

L. I. /Kudoyarov V. M. /Zhidkikh

21 | 12 15p.

Trans. of

SOURCE: [redacted], Vsesoiuznyi mauchno-issledovatel'skii institut gidrotekhniki. Izvestiia, [redacted]

Leningrad (USSR) v100 p146-153 1972.

CRREL BIBLIOGRAPHY
ACCESSIONING NO.: 28-1624 CRREL-TL-662

14

Translated by William Grimes, Inc., Hingham, Mass. for U.S. Army Cold Regions Research and Engineering Laboratory, 1977, 12p.

NOTICE

The contents of this publication have been translated as presented in the original text. No attempt has been made to verify the accuracy of any statement contained herein. This translation is published with a minimum of copy editing and graphics preparation in order to expedite the dissemination of information. Requests for additional copies of this document should be addressed to the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

037 100

Izvestiya of the All-Union Scientific Research Institute of Hydraulic Engineering, Vol. 190, 1972.

APPROXIMATE CALCULATION OF THE THERMAL REGIME OF RESERVOIRS FORMED BY A FROZEN DAM.

A.I. Pekovich, Candidate in Technical Sciences
L.I. Kudoyarov, Candidate in Technical Sciences
V.M. Zhidkikh, Candidate in Technical Sciences

The advance of the front of hydraulic energy construction into regions of Siberia and the Far East has generated a need for development of new types of hydraulic equipment, specially adapted for use under the harsh climatic conditions existing in these regions. This approach to the problem of the development of hydraulic energy in the eastern regions of the country makes it possible to take into account more fully those positive phenomena which are associated specifically with the harshness of the climate.

The accumulated experience in planning and building in northern regions shows that massive dams, erected in regions with a harsh climate, develop zones with a constant negative temperature. Taking into account the high strength characteristics and the favorable deformational characteristics of concrete in these zones, we not only can increase the reliability of the structures but can even achieve considerable economies.

The task of building frozen structures involves a number of problems, one of which is knowing the thermal regime of the part of the reservoir which is in contact with the dam, since it constitutes a warm interface with the frozen dam and foundation.

At the present time, on the basis of studies performed at VNIIG imeni B. Ye. Vedeneyev, Gidroproyekt imeni S. Ya. Zhuk and so on, so-called "Guidelines or Thermal Calculation of Reservoirs" have been worked out [1]. However, these do not consider the problem of the thermal interaction between the water and the structure.

The goal of the present paper is to provide a general scheme and practical method for calculating the thermal regime of a reservoir, taking into account the thermal interaction with the dam and the foundation and examining the possibility of regulating the thermal regime of the structure.

The joint consideration of thermal processes in the water and in the body of the structure is a very complicated problem in the theory of heat exchange. It is necessary to keep in mind that in the final analysis, in order to determine the state of the structure (including the frozen parts), it is very important to know the vertical distribution of the temperature of the water near the structure at various points in time. The problem of calculating the temperature of the water adjacent to the structure can be solved approximately in two steps.

In the first step, the calculation is applied to the temperature of the water in the part of the reservoir next to the dam, without taking into account the thermal interaction with the structure: $t = f(z,\tau)$.

In the second step, the decrease in the temperature of the water $\Delta t = \phi(z,\tau)$, arising as the result of the cooling influence of the frozen structure, is determined. For this purpose it is necessary to use the temperature distribution curves obtained in the first step of the calculation, $t = f(z,\tau)$, to find the approximate heat exchange intensity with the structure S_{approx}. If necessary, these results may be made more precise by performing a second calculation.

First of all, let us consider several aspects of the thermal regime of reservoirs which are important from the standpoint of the thermal aspects of frozen structures: we will then present our basic views on the method of calculating the water temperature and the heat exchange coefficients with the atmosphere and the body of a structure; finally, we will deal with the problem of regulating the thermal regime of structures in summer.

Analysis of data from field observations and calculations shows that the annual thermal cycle of reservoirs contains five periods [1,2]:

I. spring heating (up to 4°C)
II. summer heating (4°C and up)
III. autumn cooling (down to 4°C)
IV. cooling before ice forms (below 4°C)
V. winter (beneath ice cover)

Obviously, as far as the problem of calculating and regulating the regime of frozen structures is concerned, we are most interested in Periods II and III in this annual thermal cycle, during which the water temperature is highest. Since the changes in water temperature decrease with depth, it is advantageous to define three types of reservoirs as a function of their depth: shallow, deep, and very deep.

Shallow reservoirs are characterized by practically homogeneous temperature throughout their depth. If no ice forms, the change in the water temperature as a function of time at all depths follows the changes in air temperature, with a certain time lag; however, when the ice forms the water temperature does not exceed 0.5 to 1°C as a rule.

Deep reservoirs differ from shallow ones in having a temperature which varies as a function of depth. During periods of heating, the water may be divided vertically into three layers: an upper layer, with a relatively high temperature; a lower layer with a low temperature; and an intermediate layer, the "discontinuity layer." The latter is characterized by considerable vertical temperature gradients. The temperature changes as a function of time occur in all the layers, including the lower layer. When the ice is in place, the temperature drop as a function of depth is 2 - 3°C.

A distinguishing feature of very deep reservoirs is the small change that takes place in the water temperature in the layer near the bottom. In layers located higher up, the temperature regime resembles the regime in deep reservoirs. Using the example in Figure 1, we can show the vertical distribution and annual temperature pattern of the water in the near-bottom part of the Bratsk Reservoir for 1964. As we see, in the layers near the bottom (beginning at a depth of 30 - 40 m) the water temperature changes by no more than 2°C during the year, while the annual variations at the surface reach 22°C.

It is important to point out that the type of reservoir (depending on the depth) is a function not only of the morphometric depth h, but also of certain other factors including in particular the turbulent and free-convective mixing of the water, characterized by the value of the coefficient of thermal conductivity λ.

The method of determining the type of reservoir as a function of depth is presented in [1]. Approximately, if there are no data on field observations (for example, when the reservoir is still only in the planning stage) the type of reservoir may be determined as a function of depth as follows:

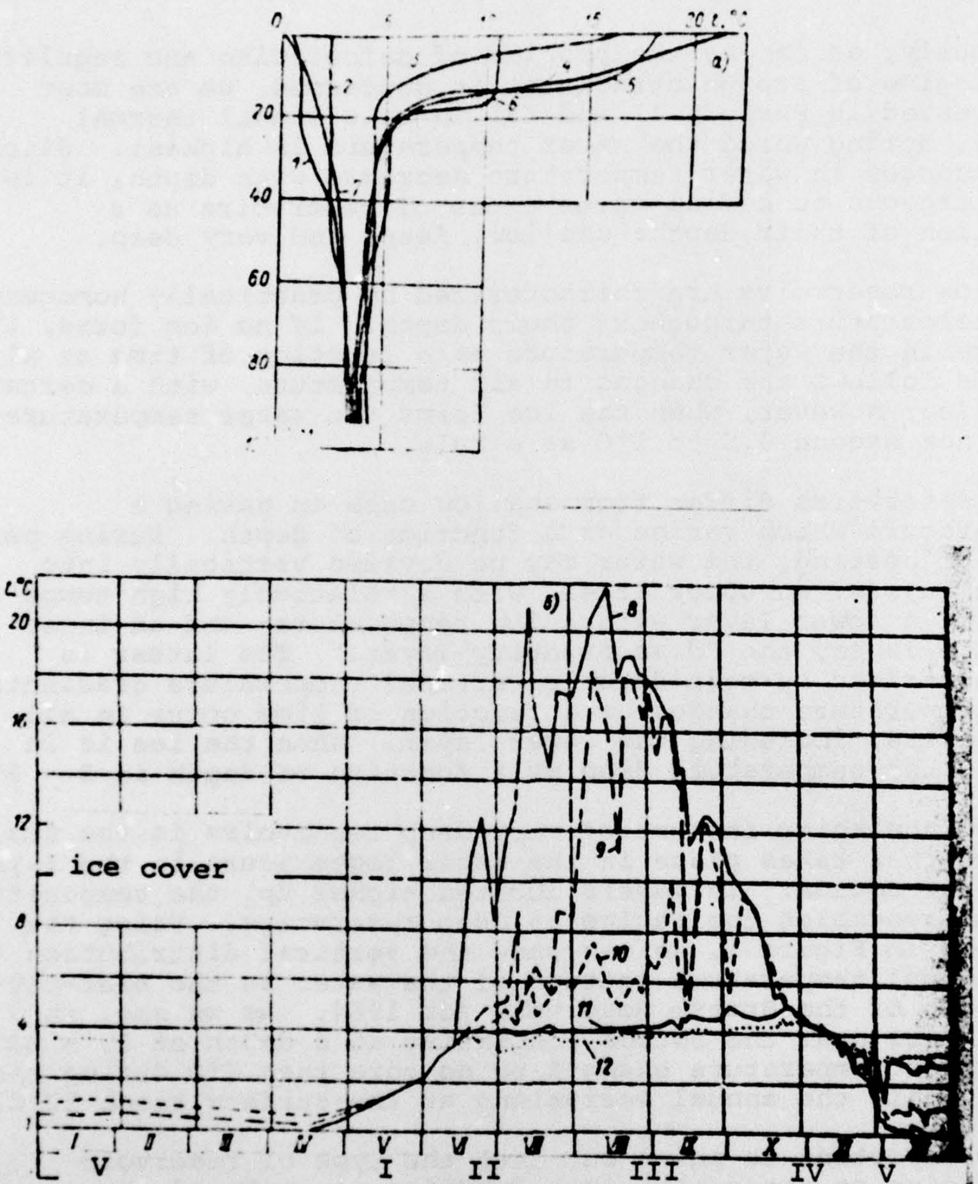

FIGURE 1. Water Temperature in the Portion of the Bratsk Reservoir near the dam for 1964: a - vertical distribution (1, April 24; 2, May 25; 3, July 14; 4, August 14; 5, August 27; 6, October 1; 7, December 24); b- annual pattern (8, at the surface; 9, at a depth of 10m; 10, at a depth of 20 m; 11, at a depth of 45 m; 12, near the bottom).

We can consider that the reservoir is "shallow" if the Biot criterion

$$Bi \equiv \frac{h}{\lambda/\alpha} < 0.2,$$

or what amounts to the same thing, the depth of the water

$$h < 0.2 \frac{\lambda}{\alpha}.$$

If Bi $\geq$ 0.2, in other words

$$h \geq 0.2 \frac{\lambda}{\alpha}$$

the reservoir will be either "very deep" or "deep." In this case, we can also consider the value of the Fourier criterion:

$$Fo \equiv \frac{\lambda\tau}{c\rho h^2}$$

When Fo $\leq$ 0.1 - 0.2, corresponding to

$$h > (2.24 \div 3.16)\sqrt{\frac{\lambda\tau}{c\rho}}$$

the reservoir will be "very deep." In the opposite case, the temperature variations will reach the bottom and the reservoir must be considered simply "deep."

Obviously, due to the problem of keeping a structure frozen year round, the most unfavorable cases are those in which the reservoir is of the shallow type, thermally speaking. If the reservoir is a deep one, especially a very deep one, the operating conditions of the frozen structures will be more favorable, since most of the heat coming from the atmosphere will accumulate in the upper water layers, and the lower layers will remain relatively cold. From this we see that the thermal regime of the structure can be regulated by raising the colder water from the deeper layers to the surface.

Now let us move on to a discussion of the method of hydrothermal calculation.

As we mentioned earlier, we shall calculate the water temperature during the warm period of the year (periods II and III in the annual thermal cycle), with the conditions for the hottest summer being used in the calculation.

To calculate the water temperature in the part of a reservoir near the bottom without taking into account the thermal interactions with the structure (stage I of the calculation) we use the method presented in [1]. The original data are the water temperature at an initial moment in time t_0, comprising the heat exchange with the atmosphere (radiation balance S_R, heat loss by evaporation S_e, convective heat exchange S_c), water depth h and coefficient of thermal conductivity of the water (λ and a). It is convenient to select $t_0 = 4°C$ as the initial temperature which occurs at the end of the first period of the annual thermal cycle; the corresponding moment in time occurs at the beginning of calculation. As a result, we find the curve for the change in water temperature as a function of depth at any moment in time used for the calculation: $t = f(z, \tau)$.

In the second stage of the calculation, we must find the decrease in temperature Δt, caused by the cooling effect of the frozen dam.

Let us break up the thickness of the water vertically into I layers with a constant water temperature in each layer; in other words, let us use the curve which we have found, $t = f(z, \tau)$ in the form of a step graph, composed of I steps. To determine Δt_i we first find the heat flux values S_{pei}, given off by the water to the frozen structure. The value of S_{pei} is determined on the basis of an approximate calculation of the thermal regime of the structure, which hereafter will be determined more specifically, taking into account the water distribution temperature found in the first stage of the calculations. Two methods of calculating S_{pei} are possible.

If we know the temperature distribution near the head limit of the structure

$$S_{pl.i} = \alpha(t_i - t_{pl.i}) \qquad (1)$$

where α is the coefficient of heat exchange; t_i and $t_{pl.i}$ are the temperatures of the water and the structure in each of the i layers, respectively.

If we know temperatures $t_{1,\ell}$ and $t_{2,\ell}$ of the structure at distances X_1 and X_2 from the head layer, then

$$S_{pl.i} = \lambda_{pl} \frac{t_{1,i} - t_{2,i}}{x_2 - x_1} \qquad (2)$$

where λ_{pl} is the coefficient of thermal conductivity of the structure.

Then, knowing the heat flux $S_{pl.\ell.}$, we determine the decrease in water temperature Δt_i at various distances from the structure at individual moments in time. This problem corresponds to the conditions in problem No. 15 in [1]. The temperature drop in each layer will be

$$\Delta t_i = \theta \frac{S_{\text{пл.}l}\, x}{\lambda}. \tag{3}$$

where $\bar{x}$ is the distance from the dam. To determine the temperature parameter θ we use a calculation graph (Figure 2) where the original argument is $Fo \equiv \frac{a\tau}{\bar{x}^2}$.

Basically, for each of the layers, we find the temperature of the water $t_{w,i} = t_i - \Delta t_i$ at individual moments in time at various distances from the dam, carrying out our calculations to a distance $\bar{x}_{approx,1}$ at which $\Delta t_i \approx 0$, i.e.,

$t_{w,i} \approx t_i$.

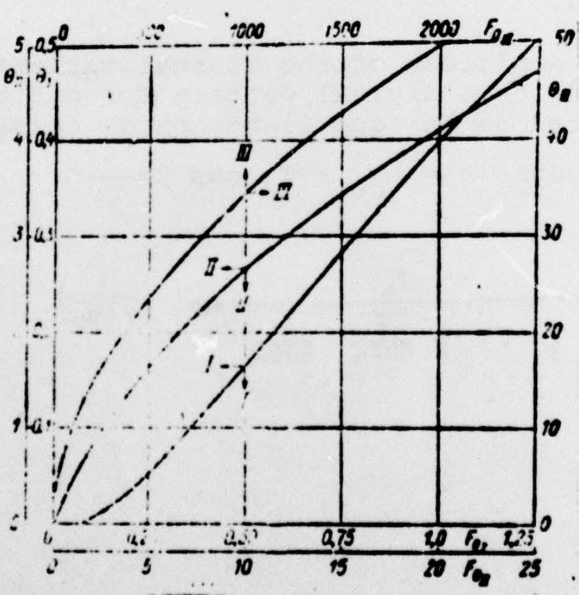

FIGURE 2. Calculation Graph to Determine Water Temperature

The method of calculating the influence of the frozen foundation on the water temperature is theoretically the same as that set forth above. The decrease in water temperature produced by heat exchange with the frozen foundation S_{bottom} will be

$$\Delta t_{\text{дн}} = \theta \frac{S_{\text{дн}}(h-z)}{\lambda}. \tag{4}$$

The temperature parameter θ is determined by the graph (Figure 2), where $Fo \equiv \frac{\alpha\tau}{(h-z)^2}$. The values of S_{bottom} are indicated approximately, taking into account the hydrothermal calculation of the water temperature near the bottom computed in the first step.

The method set forth for calculating the water temperature does not take into account the water temperature variations from day to day. However, in regions with a continental climate during the warm period of the year, day-to-day temperature variations are considerable and may turn out to have a considerable influence upon the thermal regime of frozen structures.

To determine the amplitude of the diurnal variations in water temperature, this diurnal pattern for air temperature must be represented as an equivalent cosine curve with a period τ_0 = 24 hours; $\theta = \theta_{cp} + T_\theta \cos 2\pi \frac{\tau}{\tau_0}$.
Then [3]:

$$T = \frac{T_\theta}{\sqrt{1 + 2\sqrt{\frac{\pi}{Bi^2 Fo_0}} + \frac{2\pi}{Bi^2 Fo_0}}} \exp\left(-\frac{1}{\sqrt{Fo_0}}\right). \tag{5}$$

Where T is the amplitude of the water temperature variations at depth z; T_θ is the amplitude of the temperature variations of the air; θ is the running air temperature; θ_{cp} is the average daily air temperature; $Bi^2 Fo_0 \equiv \frac{\alpha a^2 a \tau_0}{\lambda^2}$;

$Bi \equiv \frac{\alpha a^2}{\lambda}$ is the Biot criterion; $Fo_0 \equiv \frac{\alpha \tau_0}{z^2}$ is the Fourier criterion; α_a is the coefficient of heat exchange at the water-air interface; z is the distance from the surface of the water.

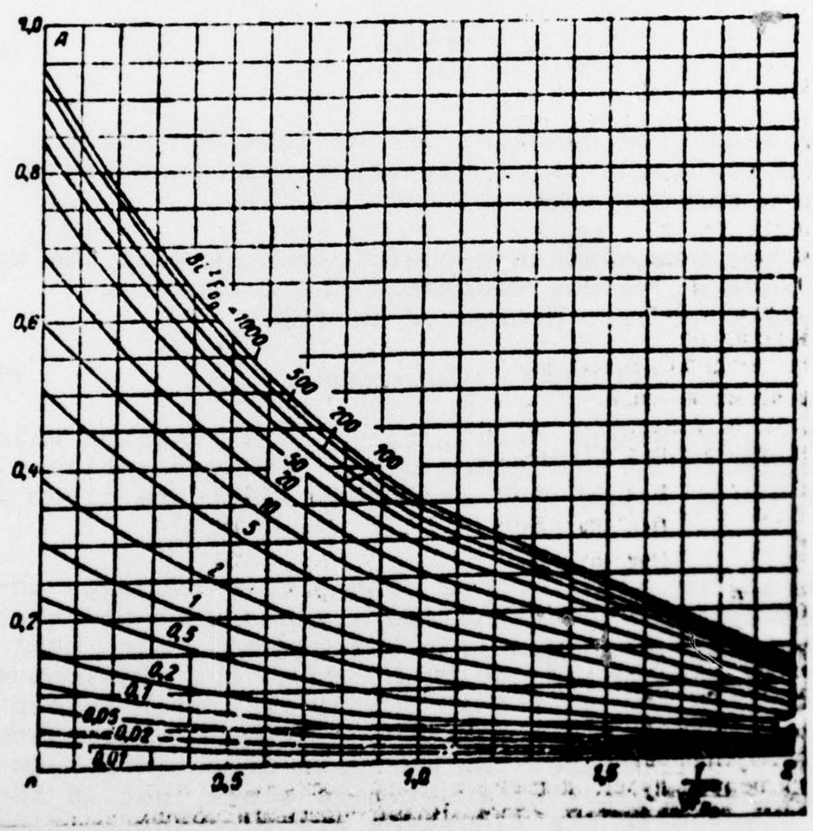

FIGURE 3. Calculation Graph to Determine Daily Variations in Water Temperature.

Using this formula, a calculation graph was plotted (Figure 3) which can be used to find the amplitude of the water temperature variations at a depth z (at known values of Bi^2Fo_0 and Fo_0):

$$T = AT_0 \tag{6}$$

or the thickness of the layer at whose lower limit the amplitude of the water-temperature variations constitutes a definite part of the amplitude of the air-temperature variations (at known values of Bi^2Fo_0 and $A = T/T_0$):

$$z = \sqrt{\frac{a\tau_0}{Fo_0}} \tag{7}$$

As the air temperature, we must use the "effective temperature:"

$$\vartheta_{эф} = \vartheta + \frac{S_R + S_H}{\alpha_a}. \tag{8}$$

Now let us discuss the question of the labelling of the heat-exchange coefficients at the water-air boundaries (α_a) and the water-structure boundaries (α).

To calculate the heat-exchange coefficient between the water and the atmosphere, we can recommend the formula of A.P. Braslavskiy et al., presented in [1]:

$$\alpha_a = 2{,}2\varepsilon[1 + 0{,}8W + f(\Delta\vartheta)],\ ккал/м^2\cdot ч. \tag{9}$$

Here W is the wind speed, m/sec; $f(\Delta\theta)$ is a function which takes into account the influence of the stratification of the air near the water layer (the values of $f(\Delta\theta)$ are given in [1]).

The question of the significance of the heat exchange coefficient between the water and the structure is one that has been little investigated. In the general case, heat exchange may take place due to both forced and free convection. To determine the heat loss coefficient with forced convection it is necessary to know the rate at which water flows around the structure. An analysis of materials on the hydraulic regime of existing reservoirs shows that in the majority of reservoirs the flowrates are very insignificant in the part near the dam. An increase in velocity occurs only in a zone located near the water-collecting structures (spillways, bottom openings, penstocks, etc.). The size of this zone is small as a rule by comparison with the total area of the head front structure. This indicates that the principal role in heat exchange between the water and the structure is played by free convection.

The value of the coefficient of heat loss α may be determined using the formulas of M.A. Mikheyev, which relate to the case of free-convective heat exchange around a wall [4]:

$$\begin{aligned} &\text{With } Ra = 1 \times 10^{-3} \text{ to } 5 \times 10^{2} && Nu = 1.18\ Ra^{1/8} \\ &\text{With } Ra = 5 \times 10^{2} \text{ to } 2 \times 10^{7} && Nu = 0.54\ Ra^{1/4} \\ &\text{With } Ra = 2 \times 10^{7} \text{ to } 1 \times 10^{13} && Nu = 0.135\ Ra^{1/3} \end{aligned} \qquad (10)$$

Here $Nu \equiv \frac{\alpha d}{\lambda_\phi}$ is the Nusselt criterion; $Ra \equiv \frac{g\beta\Delta t d^3}{\nu_\phi a_\phi}$ is the Rayleigh criterion; g is the acceleration due to gravity; β is the coefficient of thermal expansion of water; $\Delta t = t_1 - t_{pl}$; d is a critical parameter equal to the thickness of the I-th layer of water; ν_ϕ, λ_ϕ, and a_ϕ are physical coefficients of kinematic viscosity, heat and temperature elasticity of water.

We mentioned earlier that one question of great practical significance is the regulation of the thermal regime of frozen structures during the summer period, owing to the fact that colder water rises to the surface from the deeper and near-bottom layers. The possibility of hydrothermal effects upon the thermal state of the structure arises if the reservoir is of the deep or very deep type. In such reservoirs the temperature near the bottom may be 15 - 20°C cooler than the surface layers (Figure 1).

To lift the bottom water toward the surface, pumps may be used, as well as flow converters and pneumatic units. The effectiveness of these measures can be increased by installing vertically, along the front of the structure at a distance of 0.5 to 1 meter, a lightweight structure, or "curtain" (for example, a polyethylene film mounted on the body), which does not reach the bottom of the reservoir. The upper edge of this curtain must be slightly depressed below the surface of the water. This curtain considerably decreases the water and heat exchange between the cavity it forms and the rest of the reservoir. An even more effective way is to use a double curtain, which decreases heat loss through both convection and thermal conductivity.

In conclusion, we should like to point out that preliminary calculations using the method outlined above have shown that in the constant temperature area the intensity of the heat exchange between the reservoir and the structure may amount to 0.5 kW/m^2. In the variable temperature zone (down to 10 - 20 m) the intensity of the heat exchange is usually 2 to 3 orders greater. Therefore, it must be considered necessary, when it is desirable to have water temperatures which constitute the boundary condition in calculating the design of structures, to take into account the heat exchange at the water-structure interface.

REFERENCES

1. Guidelines for Thermal Calculation of Reservoirs. VSN 46 - 71 "Energiya," 1972.

2. Pekhovich, A.I.: Thermal Regimes of Bodies of Water and Streams. Materials of a Conference of the VNIIG. Gosenergoizdat, Paper No. 22, 1957.

3. Greber, G., Erk, S., and Grigull , U.: Osnovy Ucheniya o Teploobmene (Fundamentals of Heat Exchange Theory). Foreign Languages Publishing House, 1958.

4. Mikheyev, M.A.: Osnovy Teploperedachi, (Fundamentals of Heat Exchange). Gosenergoizdat, 1956.

Submitted to Press March 1972.